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Measuring energy security performance within China: Toward an inter-provincial prospective

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ABSTRACT:

China has been the world's largest energy consumer and producer for many years, yet while myriad studies have investigated Chinese performance on energy metrics compared to other countries, few to none have looked internally at Chinese provinces. This paper firstly develops a five-dimensional evaluation system centered on the energy security dimensions of availability and diversity, affordability and equality, technology and efficiency, environmental sustainability, and governance and innovation. It then correlates these dimensions to 20 distinct energy security metrics that are used to assess the energy security performance of 30 Chinese provinces, divided into eight regions. Our results reveal both trends in energy policy and practice as well as provincial status of comparative energy security for the year 2013. We find, for instance, that there is no province which performs well in all five of the energy security dimensions, and that all provinces confronted threats related to energy availability and diversity. We also demonstrate that in comparative terms, the Middle Reaches of Yellow River and the Northwest were the most energy-secure, while the Middle Reaches of Yangtze River and the Northeast were least energy-secure.

KEYWORDS: energy security; Fuzzy-AHP; PROMETHEE; sensitivity analysis; China

1. INTRODUCTION

Recently, there has been no shortage of scholarly or practitioner interest in energy security. Of particular concern is China, which surpassed the United States as the world's largest energy consumer in 2010, with a share of 20.3 percent of world total energy consumption that year¹. Energy demand in China is expected to increase 60% further from 2015 to 2035, and by the early 2030s, China could become the world's largest energy importer, overtaking Europe in terms of volume of imports, with its import dependence rising from 15% to 23%². China even became a net coal importer since 2009³, and the country's dependence on foreign oil exceeded 40 percent in 2004⁴. These resource dependence concerns also do little to address a second serious problem of climate change, which requires less fossil fuel consumption for climate change mitigation⁵. What's more, the consumption of fossil fuels causes serious ambient air pollution, leading to urban haze in major cities in eastern China, which has greatly threatened public health⁶. Further complicating matters, discussions about peak oil, price fluctuations, and energy inequality have drawn the attention of policymakers and investors, as energy security is closely related with national goals of sustainable development and economic growth⁷.

China's provinces vary greatly in energy endowment, economy development, industrial structure, technology development, and even social and cultural customs, and there is a great spatial disparity between flows of energy fuels and services within them⁸⁻¹³. Due to these disparities, energy researchers and policymakers in China are left with at least three puzzling research questions:

- (1) How can the spatial energy security trends of Chinese provinces be analyzed?
- (2) How can energy security performance be measured at the provincial level?
- (3) How can the provincial energy security of China be enhanced?

Interestingly, despite an abundance of research on energy security metrics and performance¹⁴⁻²⁰, no studies have as of yet answered these three questions. Admittedly, many studies have investigated China's energy security issues²¹⁻²⁷. For instance, Wu et al.²¹ measured China's security of energy supply with 14 indicators. Geng and Ji²⁵ developed a multi-dimensional indicator system to evaluate China's national energy security. Yang and Chen²⁷ established an evaluation framework to measure Chinese performance on energy security metrics. None, however, have looked at Chinese energy security at the provincial scale.

To do so, this study first reviews the academic literature in energy studies to present five dimensions of energy security: availability and diversity, affordability and equality, technology and efficiency, environmental sustainability, and governance and innovation. It then corresponds these to 20 different metrics and assigns them weights based on Fuzzy Analytical Hierarchy Process (an established method in the energy studies and engineering fields), and investigates the energy security performance of 30 Chinese provinces with another two methods, Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), and Sensitivity Analysis. The final parts of the article present its results and analysis as well as policy implications and conclusions.

2. DIMENSIONS AND METRICS OF ENERGY SECURITY

This section firstly reviews the conceptual underpinning of energy security, summarizing recent peer-reviewed research related to energy security dimensions and metrics.

2.1 Literature review

In the existing literature, energy security is most commonly defined as the reliable supply of energy at reasonable prices to support the economy and industry²⁸⁻³³. This traditional definition of

energy security has been critiqued for being too narrow and for downplaying broader social and environmental factors such as climate change or community acceptance³⁴. The “4A” framework of energy security (availability, accessibility, acceptability and affordability) proposed by APERC³⁵ is a more representative conception, one utilized by numerous scholars³⁶⁻³⁷.

There is no shortage of simple or aggregated indexes to measure energy security. Kruyt et al.³⁸ overviewed 24 simple and aggregated indicators for security of supply found in literature. The most widely used are reserves to production ratios, diversity indices, including Herfindahl-Hirschman index (HHI) and Shannon Wiener index (SWI)^{16, 39-41}. A noteworthy energy security index developed by International Energy Agency⁴² integrated HHI with the political stability of importing sources and energy prices. Taking a similar approach, Lefèvre⁴³ designed an energy security price index and energy security physical availability index, and used these two indices to project the energy security of France and UK over the period of 2004–2030. Based on IEA's energy security index, Löschel et al.⁴⁴ developed ex-post and ex-ante indicators of energy security, and used them to depict the energy security of Germany, Netherlands, Spain and the United States. To measure the short-term risk of energy supply, Coq and Paltseva¹⁴ developed a Risky External Energy Supply Index, which combined net import dependency, political risks of the supplying country, energy transport risks, energy fungibility and the economic importance of each energy type, and used it to measure the risks of oil, gas and coal for the EU members. By constructing the Gas Supply Security Index, Cabalu⁴⁵ combined gas intensity, net gas import dependency, ratio of domestic gas production to total domestic gas consumption and geopolitical risk, and examined the relative vulnerability to natural gas supply disruptions of seven gas-importing countries in Asia for year 2008. These indexes all make meaningful contributions in examining security of energy supply.

There are also a number of metrics of energy security that have been proposed in the literature from a more synthesized prospective. Vivoda¹⁵ proposed a set of quantitative and qualitative indicators to evaluate national or regional energy security, supposing that it consists of 11 dimensions and 44 attributes. Hippel et al.⁴⁶ devised 29 indicators of energy security including six dimensions. Unfortunately, they failed to conduct any empirical study with their instrument for any country or region. Sovacool and Mukherjee⁴⁷ developed five dimensions consisting of 20 components and 320 simple indicators along with 52 complex indicators to assess energy security. Wu et al.²¹ measured China's energy supply security with 14 indicators. Martchamadol and Kumar⁴⁸ used 19 indicators, which can be categorized into five sets, to analyze the energy security in Thailand for the period 1986-2030 in three energy scenarios presented by APERC.

2.2 Dimensions and metrics

To provide a comprehensive, yet capable and parsimonious approach to measuring energy on a provincial level, this paper synthesized such dimensions and indicators from the literature^{15, 22-23, 46-50}. Thus, we hold that energy security consists of availability and diversity, affordability and equality, technology and efficiency, environmental sustainability, and governance and innovation. As presented in Table 1, these five dimensions can be effectively decomposed into 20 components, and thereby measured with 20 metrics. We must empathize that these five dimensions have been validated by recent quantitative assessments of energy security²² as well qualitative research with energy experts¹⁷, a series of focus groups and workshops²⁰, and surveys of energy security attitudes both looking internally at China²⁴ as well as a comparative sample of eleven countries including China⁵¹⁻⁵².

2.2.1 Availability and diversity

The dimension of availability and diversity represents security of energy supply and demand, which consists of factors relating to energy resources and endowments, energy production, imports and exports, and energy consumption. We decomposed this dimension into four components in [Table 1](#): security of supply, energy potential, dependency, and diversity.

2.2.2 Affordability and equality

The dimension of affordability and equality refers to the economic aspects of energy security such as the prices of energy carriers, price fluctuations, and energy equality. Four components are included in this dimension in [Table 1](#): stability, electricity generation costs, electricity equality, and affordability of gasoline.

2.2.3 Technology and efficiency

This dimension relates to the development of energy related technologies and overall energy efficiency. It comprises four components in [Table 1](#): energy efficiency, grid efficiency, grid reliability, and capacity factors.

2.2.4 Environmental sustainability

The dimension of environmental sustainability represents the environmental and social aspects of energy production and consumption. We broke this dimension into five components in [Table 1](#): land use, water pollution, climate change, acidification, and photochemical pollution.

2.2.5 Governance and innovation

The dimension of governance and innovation regards political factors related to energy security. We utilized three components in [Table 1](#) to represent this dimension: market potential, innovation and research, and energy and environment management.

3. DATA AND METHODOLOGY

With our dimensions and metrics chosen, we proceed to collect data on our metrics and then to weight them using the principles and procedures of Fuzzy-AHP. After that, we use PROMETHEE to evaluate the energy security performance for 30 Chinese provinces. See our [Supporting Information](#) for more details on the selection and application of these methods.

3.1 Data collection and Processing

After establishing the metrics iterated above in [Table 1](#), we proceeded to collect data on them for 30 provinces in China, excluding Hong Kong, Taiwan, Macao and Tibet. All data is for 2013, and is derived from the China Statistics Yearbook and the Statistics Yearbooks of the 30 provinces published in 2014⁵³⁻⁸³, excepting for the data on carbon emissions, which came from the reference⁸⁴.

In order to achieve dimensionless analysis, data of the metrics was normalized by [Eq. \(1\)](#) and [\(2\)](#), respectively.

$$p_{ij} = (x_{ij} - \min x) / (\max x_j - \min x_j) \quad (1)$$

$$p_{ij} = (\max x - x_{ij}) / (\max x_j - \min x_j) \quad (2)$$

where p_{ij} is the normalized value of the i_{th} province with respect to the j_{th} metric, x_{ij} represents the original value of the i_{th} province with respect to the j_{th} metric, and $\max x_j$ and $\min x_j$ are the maximum and minimum value of the 30 provinces with respect to the j_{th} metric.

3.2 Multi-criteria Decision Making Methods

To provide weights to the data and evaluate energy security performance for 30 Chinese provinces, this study chose two types of Multi-criteria Decision Making methods: Fuzzy Analytical Hierarchal Processes (Fuzzy AHP) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). Fuzzy AHP is frequently used to capture expert knowledge of a preference numerically, and applied to solving hierarchical and complex decision-making problems⁸⁵. Fuzzy AHP uses a membership function to calculate a grade of membership that a given variable belongs to, and triangular and trapezoidal functions are usually used in fuzzy logic because they are simple to use but also accurate⁸⁶⁻⁹⁰. The PROMETHEE method is one of the most recent MCDA techniques, firstly developed by Brans⁹¹. It has witnessed a rapid proliferation throughout academic research, with several hundred articles published in more than 100 scholarly journals since 1985⁹². Again, the [Supporting Information](#) provides more details to the specific equations and formulations utilized in our Fuzzy AHP and PROMETHEE execution.

4. RESULTS AND ANALYSIS

With the dimensions and components of energy security presented in [Table 1](#), the pairwise comparisons with respect to the five dimensions and the components in each dimension were determined based on formulations presented in the [Supporting Information](#). Then, we used Visual PROMETHEE to evaluate the energy security of China's 30 provinces for the calendar year 2013.

Table 2 and Figure 1 present our results of provincial energy security performance measurement. The value of Phi is the net outranking flows with respect to the 30 provinces of China, and the Score is the normalized value of Phi according to Eq. (1). The greater the value of Phi or the score, the more secure the energy supply of the corresponding province would be. This data suggests that Shaanxi (0.2413), Shanxi (0.1430), Ningxia (0.1344), Anhui (0.1150), and Qinghai (0.1086) were the five most energy-secure provinces in 2013. All of them are middle and western provinces, rich in energy resources. By contrast, Guangxi (-0.1752), Jilin (-0.1642), Shanghai (-0.1638) Hubei (-0.1601), and Liaoning (-0.1594), performed the worst on energy security metrics for 2013.

According to the varying levels of economic development and geography, the 30 provinces can also be divided into eight regions to provide analysis at a higher scale, namely Northern Coast, Eastern Coast, Southern Coast, Northeast, Middle Reaches of Yellow River, Middle Reaches of Yangtze River, Northwest, and Southwest, regions which are shown in Figure 2. It is apparent that the Middle Reaches of Yellow River performs the best on energy security, since most of China's energy resources locate in this region. This is followed by the Northwest, also a region where energy resources are significant. The Southwest, Southern Coast and Northern Coast are in the third group, and they have achieved moderate energy security performance. However, the Eastern Coast, Middle reaches of Yangtze River, and the Northeast, perform the worst energy security performance.

The next phase of our methodology involved further analyzing the results with PROMETHEE network (see Figure 3). More specifically, the Middle Reaches of Yellow River and the Northwest have the most significant energy reserves and levels of production in China, but these have been compromised by threats to economic development including weakening infrastructure and environmental degradation. The Southwest, Southern Coast and Northern Coast show a moderate

energy security performance. The Eastern Coast, the most economically vibrant area of China, performs poorly due to high levels of consumption, growing dependence on imports, and environmental degradation. Similarly, the Middle Reaches of Yangtze River, lacking fossil fuels and lagging behind the coastal provinces in terms of economic development, performs relatively poorly as well. The worst energy security performer is the Northeast region, whose situation is similar to the Middle Reaches of Yangtze River.

Interestingly, our analysis suggests that the provinces in the Middle Reaches of Yellow River, Northwest, and Northern Coast have shown little variance in their energy security performance. Sichuan, Yunnan and Guizhou, where most of energy resources in Southern China reside, demonstrates relatively high performance. Chongqing and Guangxi show extremely poor energy security performance. The same situation has been observed in the Southern and Eastern Coast regions, where both Hainan and Shanghai show much lower scores of energy security compared with their neighbors. On the contrary, Anhui, rich in coal, has a much better energy security performance than the other three provinces in this region, while Heilongjiang, rich in petroleum, performs better with respect to energy security than Liaoning and Jilin.

The performance score of each dimension for the 30 provinces are shown in [Table 3](#). Grouping the 30 provinces into eight regions, the performance score with respect to each region was determined by calculating the average scores presented in [Figure 4](#).

According to [Figure 4](#), it is apparent that the best energy security performance across all provinces relate to the dimension of affordability and equality, with an average score of 70.40. Chinese provinces demonstrate a moderate performance on technology and efficiency (54.89), environmental sustainability (51.18), and governance and innovation (55.37). Chinese provinces perform the worst on the dimension of availability and diversity (31.58). In addition, there is rather

great variance among the eight regions across three dimensions, namely, availability and diversity which range from 14.93 to 72.35, affordability and equality which range from 39.36 to 91.08, and technology and efficiency which range from 38.27 to 90.21. The other two dimensions, environmental sustainability (ranges from 34.83 to 72.14), and governance and innovation (ranges from 45.20 to 66.53), show smaller variances. Thus, it could be concluded that energy availability and diversity are the main challenges facing China's energy security at the national level.

Moreover, the Middle Reaches of Yellow River and the Northwest show the best performance on availability and diversity. The Eastern Coast, Southern Coast and Northwest are the three regions who perform best on affordability and equality. The Eastern Coast, at the same time, demonstrates a much higher performance on the dimension of technology and efficiency than any other regions. As to the dimension of environmental sustainability, Southern China, including the Southern Coast and Southwest, do better than other regions. As shown above, the eight regions indicate a small variance with each other on the dimension of governance and innovation, but the coastal provinces do perform better than inland provinces.

Lastly, a Sensitivity Analysis was given to the 30 provinces. Firstly, it distributed equal weight to every metric, in which case, a Phi could be obtained for each province, which can indicate their energy security performance. Then, 20 scenarios were proposed, and in the i -th scenario, the weight of the i -th metric equals 0.24, while the weights of the rest metrics equal 0.04. For each scenario, the energy security performance for each province can be computed. Subsequently, the Sensitivity Analysis Factor (SAF) could be calculated, which measures how much a province's energy security performance has change when the weight of a particular metric change from 0.05 to 0.24. After that, the results of Sensitivity Analysis with respect to the eight regions are calculated, as shown in [Figure 5](#). The positive SAF means that the energy security performance is enhanced,

while the negative SAF means the performance is weakened. The greater the absolute SAF, the more sensitive the performance is.

Figure 5 also illustrates that the dimension of availability and diversity causes the greatest sensitivity on energy security performance, with an absolute SAF of 0.32, the technology and efficiency, and environmental sustainability lead to a moderate sensitivity, with the absolute SAFs of 0.20 and 0.23, respectively. Energy security performance is least sensitive to the dimension of affordability and equality (absolute SAF is 0.12), and governance and innovation (absolute SAF is 0.13). Specifically, the energy security performance of the Northwest and the Middle Reaches of Yellow River would be greatly enhanced by the increasing the weight of metrics related to availability and diversity, while that of the Eastern Coast and Southern Coast would be severely weakened. The performance of the Eastern Coast and Northern Coast would be improved if the metrics about technology and efficiency were weighted more, but the performance of the Northwest, Southwest and Northeast would suffer. When the metrics about environmental sustainability increase in weight, the Southern Coast, Middle Reaches of Yangtze River and Southwest would benefit while the Northwest, Middle Reaches of Yellow River, and Northern Coast would see performance decline.

5. CONCLUSIONS AND POLICY IMPLICATIONS

Our results do suggest some salient policy implications for enhancing China's energy security and bridging the gap in energy security performance among different provinces and regions.

Firstly, our data strongly implies that developing renewable sources of electricity and alternative fuels for transport (usually called "New Energy Vehicles" in China) would improve energy security performance and diversify the energy mix. Since energy availability and diversity

were determined by our analysis to be the most severe threat facing China's energy security as a whole, national and provincial planners need to invest in more reliable energy sources. China has great renewable energy potential, which can not only maintain its security of energy supply and contribute to diversification, it can also create more jobs and reduce environmental pollution. Coastal provinces in particular, substantial consumers and importers, should find ways to increase such local sources of energy supply. With their comparatively more advanced science and technology sectors, offshore wind power and biofuels perhaps have the most appeal. The Middle Reaches of Yangtze River are gifted with great hydropower and biofuel potential. The Southwest is richest in hydropower as well as unconventional fuels such as shale gas. Each of these resources should be developed to diversify China's energy supply mix.

Secondly, improvements in energy efficiency are needed. On the one hand, most of China's energy resources spatially distant from consumers and located far inland, for instance, coal reserves, existing solar PV deployment, and installed onshore wind power remains in the Middle Reaches of Yellow River and the Northwest; oil and gas reserves are situated in the Northeast and Northwest; hydropower resources are utilized primarily in the Southwest and Middle Reaches of Yangtze River; and biofuel sources are concentrated in Southern China. On the other hand, the inland provinces perform much worse than the coastal provinces on technology and efficiency, and have fewer R&D expenditures and less established infrastructure. Improvements in energy efficiency can optimize the whole life cycle the energy industry, including exploitation, production, processing, transmission and consumption. Thus, R&D on energy efficiency systems such as smart meters, improved distribution networks to minimize transmission losses, and enhancements to residential, commercial, and industrial building stock is quite beneficial and urgent.

Thirdly, more attention and investment should be paid to mitigating environmental problems and improving environment quality. Though the government has promised that by 2020 China would reduce its carbon intensity by 40 to 45 percent compared to 2005 levels, people remain embroiled in severe environment problems, especially those associated with the mining, processing, combustion, and waste of coal. The government should enforce the adoption of better pollution controls on coal-fired power plants and increase responsible for public infrastructure projects for energy conservation and environment improvement, such as public green spaces and charging stations for electrical vehicles.

Lastly, national Chinese energy strategy should be adjusted to balance development among different regions and provinces. The coastal provinces have strengthened their economies for several decades since the Reform and Opening, and Western China, including the Northwest, Southwest, and a part of Middle Reaches of Yellow River, is under development with the deployment of the Development of the Western Region in China since 2000. However, the Central region of China, including the Middle reaches of Yangtze River, Northeast, and another part of Middle Reaches of Yellow River, have been neglected by national strategy, and show suboptimal energy security performance, a phenomenon termed “Central Sinking” by some scholars⁹³. The Northeast, who used to be called as the “Eldest Son of the Republic” for its contribution in the planned economy era⁹⁴, now also performs poorly on various economic and demographic metrics. Thus, senior Chinese decision makers should focus more on investing in and improving the energy security of the Central Region.

For those outside of China, the study also reveals the complexity of energy security as both a concept and by location. Energy security performance can vary greatly across geographic space. Many provinces in Western China perform much better than the developed coastal provinces.

Western provinces, for instance, perform much better in terms of energy availability. More importantly, their relative advantage has been amplified by a smaller population so they can enjoy more energy endowments and resources per capita. The lesson here is relatively simple: Chinese performance on energy security differs greatly within its regions and provinces. Thus, energy analysts should begin to take a far more nuanced approach when they partake in energy security assessments.

ASSOCIATED CONTENT

Supporting Information

The additional information is provided including the procedure of research methods and data tables. This material is available free of charge via the internet at <http://pubs.acs.org>.

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Author Contributions

All authors took part in this study and contributed equally to this manuscript. Long Zhang and Jingzheng Ren were responsible for the data collection and analysis, and wrote the main part of

the manuscript. Benajamin K. Sovacool and Jing Yu supervised the research and contribute significantly to the organization of the manuscript.

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TABLES AND FIGURES

Table 1. Dimensions, components and metrics of energy security

Dimensions	Components	Metrics	Unit	Definition	Preference
A_1 : Availability and diversity	A_{11} :Security of supply	I_1 : Primary energy production per capita	tce	Comprises the production of coal, crude oil, natural gas and other new and renewable energy.	Greater preferred
	A_{12} :Energy potential	I_2 : Fossil fuel reserves per capita	tce	Proven recoverable reserves at the end of a given year divided by total local population.	Greater preferred
	A_{13} : Dependency	I_3 : Self sufficiency	%	Ratio of total primary energy production divided by total primary energy consumption.	Greater preferred
	A_{14} : Diversification	I_4 : Diversity of energy consumption	-	$SWI = \sum_{i=1}^m p_i \ln(p_i)$	Greater preferred
A_2 : Affordability and equality	A_{21} :Stability	I_5 : Stability of gasoline prices	-	Standard deviation of gasoline prices divided by the average price.	Greater preferred
	A_{22} :Electricity generation cost	I_6 : Coal-fired power tariff	Yuan/k Wh	Actual prices paid by the electricity grid to power plant for the electricity.	Smaller preferred

	A_{23} : Electricity equality	I_7 : Share of electricity in total energy consumption	%	Annul electricity consumed divided by local total energy consumption.	Greater preferred
	A_{24} : Affordability of gasoline	I_8 : Quantity of gasoline bought with GDP	10^4 tons per person	Local per capita GDP divided by the average gasoline prices for a given year.	Greater preferred
	A_3 : Technology and efficiency	A_{31} : Energy efficiency	I_9 : Energy intensity	tce/ 10^4 Yuan	TPES in tons of standard coal equivalent per 10000 yuan of GDP.
	A_{32} : Grid efficiency	I_{10} : Electricity transmission and distribution losses	%	Including losses in transmission between sources of supply and points of distribution and in the distribution to consumers.	Smaller preferred
	A_{33} : Grid reliability	I_{11} : Average blackout hours per household	Hours	Annual blackout hours per household.	Smaller preferred
	A_{34} : Capacity factor	I_{12} : Utilization of power plants	%	Annual operation hours of power plants divided by the total hours for a year.	Greater preferred
A_4 :	A_{41} : Land use	I_{13} : Forest coverage	%	Forest area divided by local land area.	Greater preferred

Environmental sustainability	<i>A</i> ₄₂ : Water pollution	<i>I</i> ₁₄ : Waste water emissions per capita	Tons per person	Annual tons of emitted wasted water divided by local population.	Smaller preferred
	<i>A</i> ₄₃ : Climate change	<i>I</i> ₁₅ : GHG emissions per unit of GDP	tce /10 ⁴ Yuan	Annual tons of carbon dioxide emissions from fuel combustion divided by local population.	Smaller preferred
	<i>A</i> ₄₄ : Acidification potential	<i>I</i> ₁₆ : Sulfur dioxide emissions per capita	Tons per person	Annual tons of sulfur dioxide emissions from fuel combustion divided by local population.	Smaller preferred
	<i>A</i> ₄₅ : Photochemical potential	<i>I</i> ₁₇ : Nitrogen dioxide emissions per capita	Tons per person	Annual tons of nitrogen dioxide emissions from fuel combustion divided by local population.	Smaller preferred
	<i>A</i> ₅₁ : Market potential	<i>I</i> ₁₈ : Investment in energy industry	%	Ratio of investment in energy industry divided by total local investment.	Greater preferred
Governance and innovation	<i>A</i> ₅₂ : Innovation and research	<i>I</i> ₁₉ : Research intensity	%	Ratio of local government expenditure on R&D divided by government total expenditures.	Greater preferred
	<i>A</i> ₅₃ : Energy & environment management	<i>I</i> ₂₀ : Energy saving & environment protection	%	Ratio of local government expenditure on energy saving & environment protection divided by government total expenditures.	Greater preferred

Source: research interviews, brain storming, and workshop discussion.

Table 2. The results of Energy Security Performance for 30 Chinese Provinces

Rank	Province	Phi+	Phi-	Phi	Score
1	SHAANXI	0.4216	0.1803	0.2413	1.0000
2	SHANXI	0.3853	0.2423	0.1430	0.7640
3	NINGXIA	0.3967	0.2623	0.1344	0.7433
4	ANHUI	0.3398	0.2248	0.1150	0.6968
5	QINGHAI	0.3894	0.2808	0.1086	0.6814
6	INNERMONGOLIA	0.3647	0.2639	0.1007	0.6624
7	YUNNAN	0.3434	0.2472	0.0961	0.6514
8	SICHUAN	0.3190	0.2400	0.0790	0.6103
9	HEILONGJIANG	0.3333	0.2565	0.0768	0.6050
10	XINJIANG	0.3505	0.2777	0.0728	0.5954
11	GANSU	0.3300	0.2627	0.0673	0.5822
12	GUIZHOU	0.3320	0.2913	0.0406	0.5181
13	GUANGDONG	0.3093	0.2721	0.0372	0.5100
14	HENAN	0.2887	0.2615	0.0272	0.4860
15	FUJIAN	0.3012	0.2753	0.0258	0.4826
16	SHANDONG	0.2847	0.2786	0.0061	0.4353
17	JIANGSU	0.2949	0.2913	0.0037	0.4295
18	ZHEJIANG	0.2881	0.2923	-0.0042	0.4106
19	BEIJING	0.2808	0.3009	-0.0201	0.3724
20	TIANJIN	0.2901	0.3254	-0.0353	0.3359
21	HEBEI	0.2548	0.3195	-0.0647	0.2653

22	CHONGQING	0.2422	0.3160	-0.0738	0.2435
23	JIANGXI	0.2364	0.3221	-0.0858	0.2146
24	HAINAN	0.2284	0.3495	-0.1211	0.1299
25	HUNAN	0.2028	0.3507	-0.1478	0.0658
26	LIAONING	0.1974	0.3567	-0.1594	0.0379
27	HUBEI	0.1944	0.3544	-0.1601	0.0363
28	SHANGHAI	0.2209	0.3847	-0.1638	0.0274
29	JILIN	0.2116	0.3759	-0.1642	0.0264
30	GUANGXI	0.1891	0.3644	-0.1752	0.0000

Table 3. Energy Security Performance Scores for 30 Chinese provinces

Province	Performance Score				
	A ₁	A ₂	A ₃	A ₄	A ₅
BEIJING	16.65	80.45	66.07	52.14	53.65
TIANJIN	25.88	62.31	56.63	33.50	60.14
HEBEI	18.60	63.58	64.14	41.26	70.70
SHANXI	100	57.92	44.20	39.22	68.82
INNERMONGOLIA	93.09	64.12	34.47	36.65	60.66
LIAONING	20.41	45.37	42.88	38.33	48.71
JILIN	20.14	34.72	34.98	51.57	63.38
HEILONGJIANG	39.93	37.99	43.48	59.62	55.15
SHANGHAI	14.05	77.30	89.69	35.93	42.76
JIANGSU	16.20	95.93	100	36.21	67.38
ZHEJIANG	14.55	100	80.96	52.55	56.13
ANHUI	27.71	73.22	66.12	53.94	47.45
FUJIAN	17.11	86.03	62.26	61.88	55.71
JIANGXI	16.63	71.16	54.22	67.59	36.99
SHANDONG	22.43	63.32	75.67	37.38	81.61
HENAN	23.95	68.74	69.61	45.58	42.81
HUBEI	16.61	56.99	53.26	52.50	49.99
HUNAN	18.54	54.59	39.10	69.19	51.37
GUANGDONG	15.17	97.56	70.32	54.53	100
GUANGXI	15.30	72.76	37.68	68.46	37.46

HAINAN	16.12	74.38	37.45	100	35.07
CHONGQING	22.83	58.38	41.45	47.14	64.40
SICHUAN	25.71	64.61	62.52	71.09	44.88
GUIZHOU	48.44	62.78	34.18	53.52	37.85
YUNNAN	32.98	73.95	36.71	80.51	41.43
SHAANXI	72.36	62.95	60.41	58.75	57.34
GANSU	31.47	82.58	38.86	44.1	48.85
QINGHAI	57.52	92.87	28.83	35.51	64.69
NINGXIA	55.09	88.53	48.79	28.25	54.63
XINJIANG	66.14	77.79	36.61	31.44	42.19

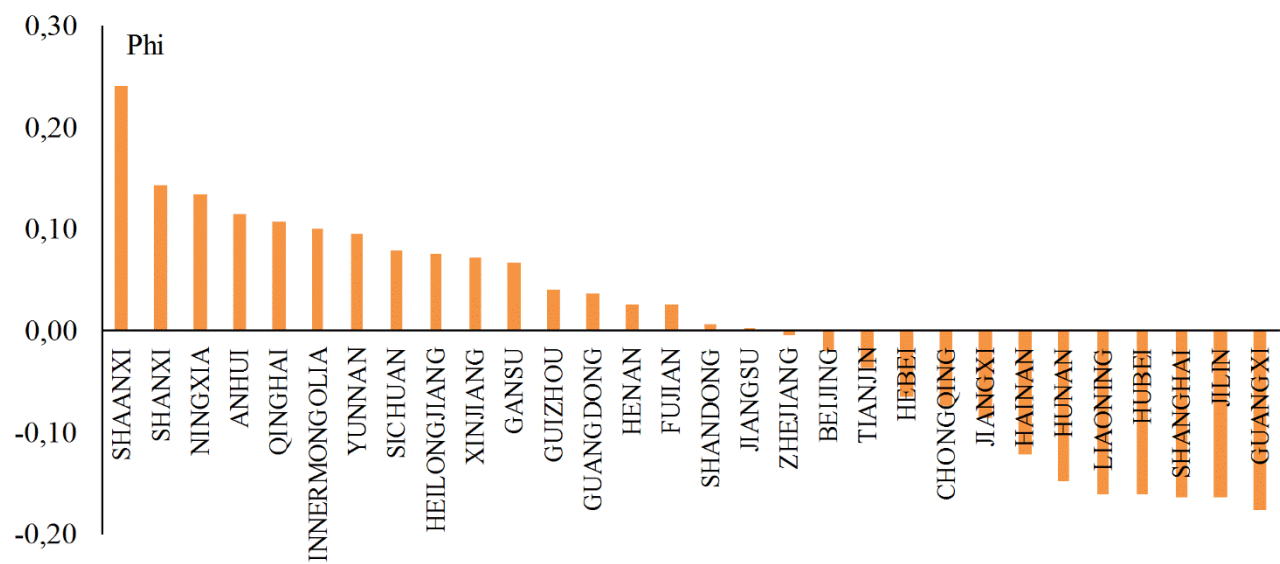


Figure 1. Net energy security flow ranking 30 Chinese Provinces

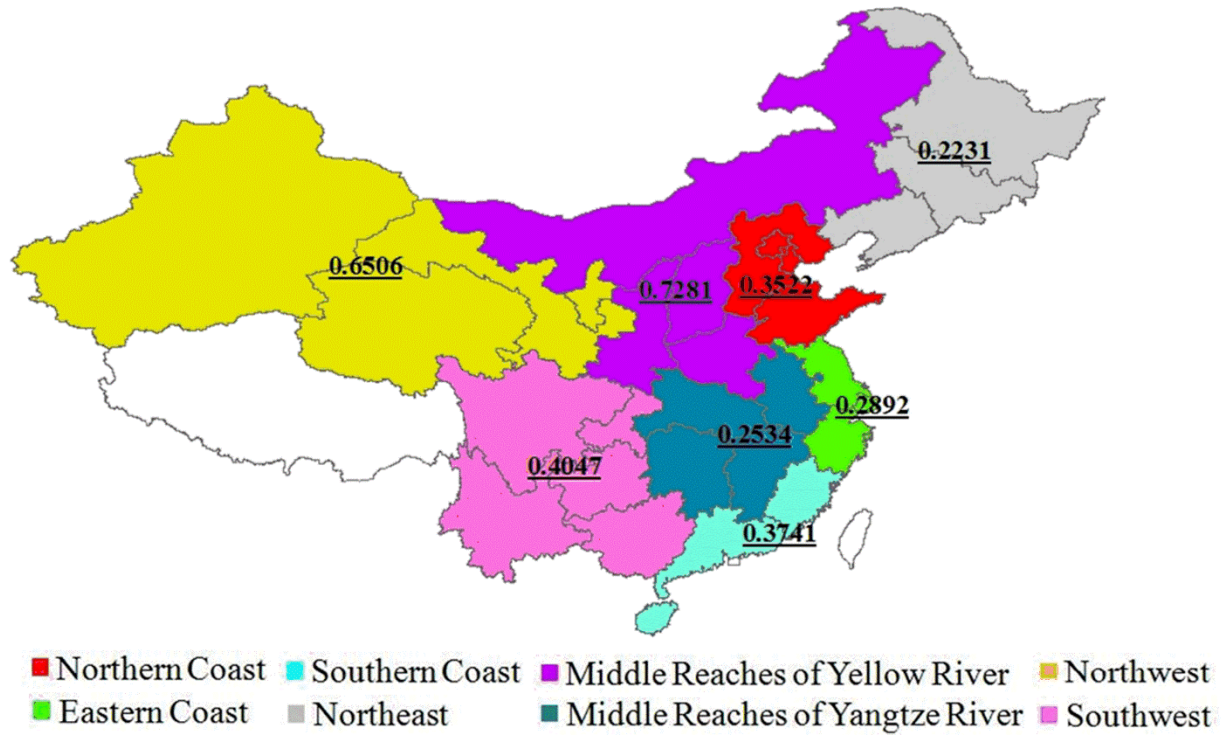


Figure 2. The average energy security performance of eight Chinese regions

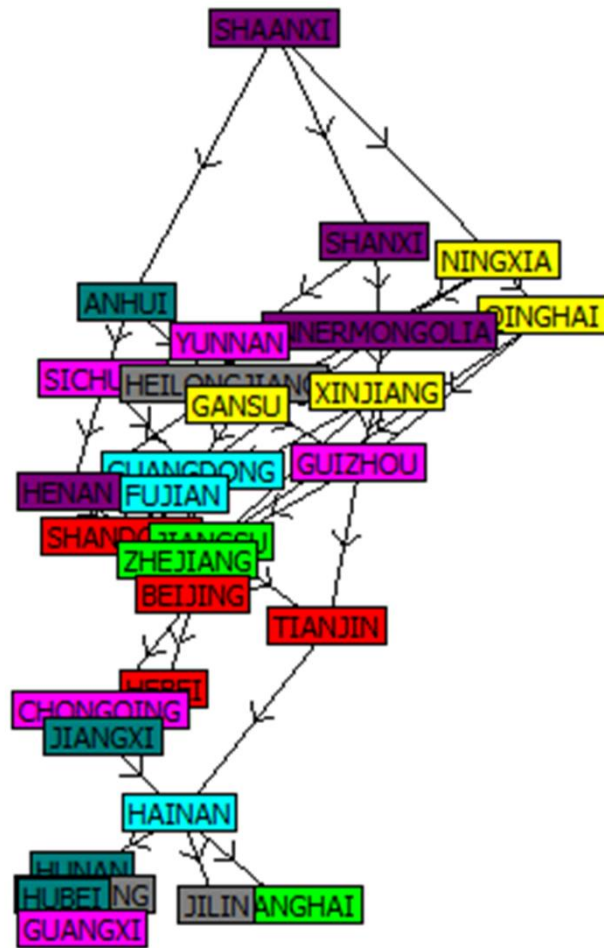


Figure 3. The Visual PROMETHEE network of Energy Security Performance for 30 Chinese Provinces

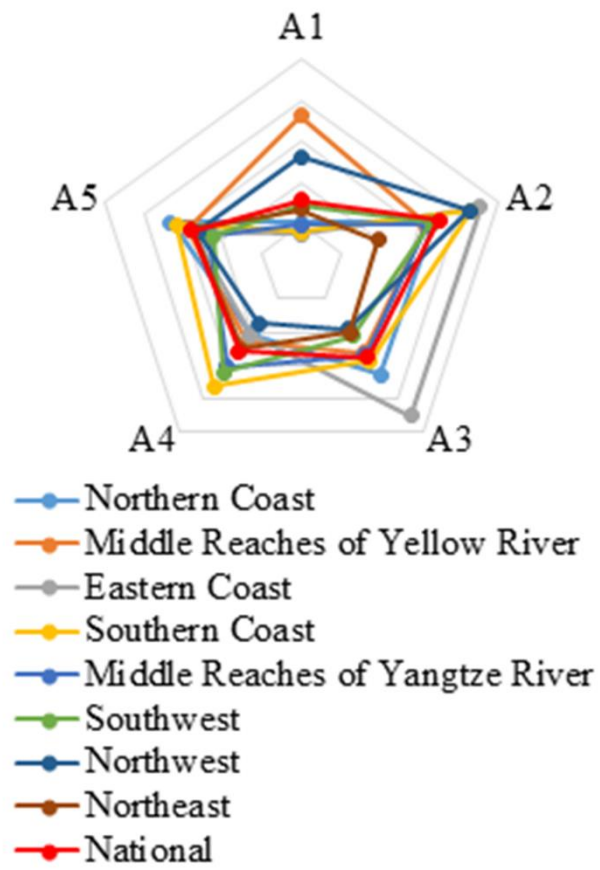


Figure 4. Energy security performance scores for eight Chinese regions

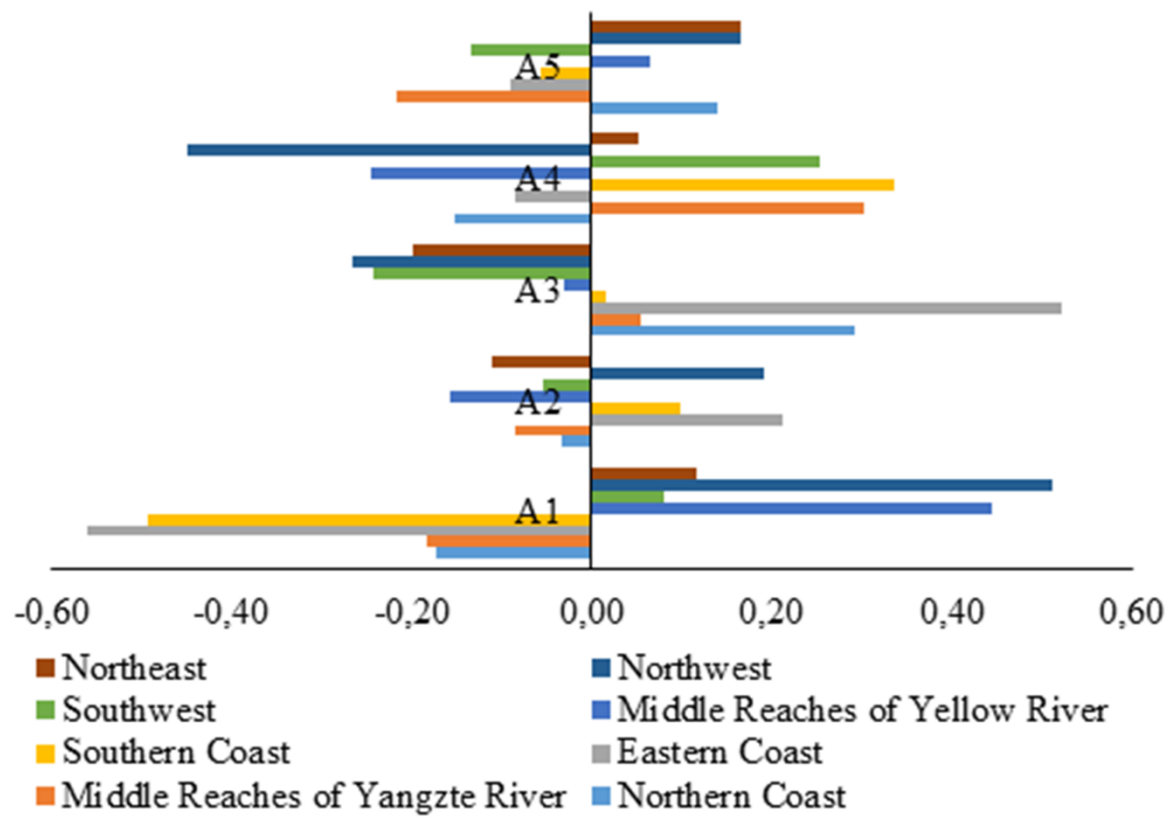


Figure 5. The result of our Energy Security Performance Sensitivity Analysis

TOC Graphic

